



UNITED STATES ENVIRONMENTAL PROTECTION AGENCY  
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December 14, 2016

**MEMORANDUM**

SUBJECT: Geologic review and comments on proposed Wieben 2-13 injection well and Wasatch Formation, Mamm Creek Field, Piceance Basin, Colorado

FROM: Treasure Bailey, Aquifer and Aquatic Resources Protection

TO: Wendy Cheung, UIC

The injection of waste fluids via the Wieben 2-13 well into the Atwell Gulch and Molina Members of the Wasatch Formation has been proposed, with the Shire Member purported by the applicant (Encana Oil & Gas (USA) Inc.) to serve as a confining unit. The following is a review of the Wasatch Formation and structural geology in the area of the proposed Wieben 2-13 injection well. This review took place over the spring and summer of 2016 but has been combined with a geochemical review by Greg Oberley (also from summer 2016) to form one document for the file.

**Sedimentology and Groundwater Use of the Wasatch Formation in the Mamm Creek Area**

Deposition of the Wasatch Formation took place from the Late Paleocene to the Middle Eocene. In the southern parts of the Piceance basin, in the Mamm Creek Field, the Wasatch Formation is composed of three members, from oldest (deepest) to youngest (shallowest): Atwell Gulch Member, Molina Member, and Shire Member. The Atwell Gulch Member overlies a regional unconformity and is composed of variegated mudstone and fluvial sand bodies. The Molina Member is generally sand-dominated amalgamated channel deposits and in the Mamm Creek area the Shire Member is composed of paludal and floodplain muds (~80%) and fluvial sands (~20%; URS 2006).

Approximately 90% of all permitted groundwater wells in the Mamm Creek field are screened in the Wasatch Formation (in Atwell Gulch, Molina or "Molina-like" and Shire Members), where flow is enhanced by the presence of natural fractures (URS 2006). Groundwater analyzed from Wasatch wells in the southern Piceance basin have chemistries reflecting mixing of more than one source (eg. Albrecht, 2007, McMahon et al., 2010, McMahon et al., 2012, Thyne, 2008, URS, 2006). McMahon et al. (2012) attribute mixing of young and older (deeper) saline groundwater present in the Wasatch Formation in the Piceance Basin south of the Colorado River to the lack of a laterally extensive confining layer within the Wasatch. Despite the current groundwater use and uncertainty regarding a laterally extensive confining layer within the Wasatch, the injection of waste fluids via the Wieben 2-13 well into the Atwell Gulch and Molina Members of the Wasatch Formation has been proposed, with the Shire Member purported by the applicant (Encana Oil & Gas (USA) Inc.) to serve as a confining unit. The applicant notes that mapping the basal Wasatch contact (below the proposed injection zone) over broad areas is also difficult due to highly variable lithology (as described by Donnell (1969) and reported by Encana, 2015).

Although the Wasatch is not historically economically productive for fluid minerals in the Mamm Creek field, in some places Wasatch sands are charged with gas from the underlying Mesaverde

Group (Johnson and Flores, 2003), which migrated from the Williams Fork Formation, likely “along extensive fracture systems that have been documented by Pitman and Sprunt (1986)” (Johnson and Rice, 1990).

### **Geologic Setting and Groundwater Transport Mechanisms near Proposed Wieben Injection Well**

The presence, age, and location of geologic structures relative to the proposed Wieben injection well is important in that it has generally been demonstrated that enhanced vertical permeability and fluid (water and hydrocarbon) migration is facilitated through natural fracture networks and other geologic structures, even in low permeability formations. For instance, in their investigations related to water contamination in the Mamm and Divide Creek fields, Thyne (2008) and McMahon et al. (2010) describe the potential for GW communication through natural fractures, even when a confining unit exists. Similarly, Encana (2005), as referenced in Thyne (2014) also describes fluid migration through the Wasatch (including through the Shire “aquitard” as described by Encana 2015) to the surface, facilitated by young faults and fractures.

The Wieben well sits just to the east of the axis of the Basin Syncline, and approximately 8 miles west of the Divide Creek Anticline (Albrecht 2007, Encana 2015, Grout and Verbeek 1992, Tremain and Tyler 1995, Tyler, 1996, URS 2006). A northeast-trending basement fault with a coincident shallow aeromagnetic anomaly has been identified to the north and east of the proposed disposal site (Hoak and Klawitter 1997, URS 2006), and extensional normal faults have also been identified within the field, which in some cases intersect with older basement faults (Hoak and Klawitter 1997, Grout et al., 1991, URS 2006). Four sets of joints occurring in the Green River, Wasatch, and Mesaverde Formations have been mapped throughout the Mamm Creek field and vicinity of the proposed injection zone (Grout and Verbeek, 1992, Tremain and Tyler, 1996, URS 2006). See Figure 1 (from URS 2006) for a structural overview including major faults and fractures, folds, lineaments, and aeromagnetic anomalies.

In their Piceance Basin fracture review Pitman and Sprunt (1986) describe complex fracture relationships in the Wasatch Formation as “somewhat more complex than those reported for the overlying Green River Formation and the underlying Mesaverde Group.” They continue that “Verbeek and Grout (1984) have shown that the fracture systems normally found in the Mesaverde locally extend into higher stratigraphic levels of the Wasatch and are seen in some surface exposures of the Wasatch Formation. Elsewhere, outcrops of the Wasatch Formation are dominated by joints that can be traced upward into the Green River Formation (Verbeek and Grout, 1984). The Wasatch Formation, therefore, contains fracture sets of two different patterns: one characteristic of the older Mesaverde Group and the other characteristic of the younger Green River and Uinta formations.” These studies demonstrate a lack of stratigraphic control, meaning vertical fractures in the Wasatch are not necessarily bed-bound and are therefore more likely to act as conduits for fluid movement between formations.

Pitman and Sprunt (1986) also evaluated core and well log reports from eastern portions of the Piceance Basin and note that “abundant open and mineralized fractures extend from the Paleocene and Eocene Wasatch Formation down through the Upper Cretaceous Mesaverde Group, a thickness of thousands of feet.” Cores from near the Rulison field just west of Mamm Creek Field also “show evidence of extensive fractures through more than 8,500 ft (2,600 m) of Cretaceous and Tertiary

section,” (Pitman and Sprunt, 1986) further demonstrating that fractures are not contained to discrete stratigraphic intervals in the Wasatch.

In their 2006 Hydrogeologic Characterization of Mamm Creek field, URS conducted lithologic field studies and also evaluated whole core from the Wasatch Formation from Encana’s Moore 33-10A well, ~6 miles northeast of the proposed disposal well. In their lithologic field evaluation, URS noted high angle conjugate fracture sets in the mudstones, significant because fracture related permeability resulting from conjugate fracture pairs would be greater than that resulting from sub-parallel fracture sets (Lorenz, 1999). In their evaluation of the Wasatch core, URS (2006) noted vertical fractures in both the sand and mudstone and that vertical fractures in the mudstone were easier to identify in the whole core versus outcrop (and arguably from well logs). URS described the vertical fractures as forming “macropores in the rock matrix, which often have higher vertical hydraulic conductivities than the surrounding rock,” providing “conduits for vertical movement of water and other fluids.” The authors noted “a black-colored silt-filled vertical to sub-vertical fracture was observed in the Moore well core at a depth of 607 to 616 feet. Color zonation (gray halos) extended into the surrounding red rock matrix from the fracture aperture, indicating movement of fluids with reducing geochemical characteristics migrated within the fracture aperture.”

#### **Groundwater Contamination in the Southern Piceance and Mamm Creek Area**

Several studies (eg. Albrecht, 2007, McMahon et al., 2010, McMahon et al., 2012, Thyne, 2008, URS, 2006) demonstrate correlations between geologic structures and/or oil and gas production activities with the migration of deep fluids into the shallow Wasatch in the southern Piceance basin. Albrecht (2007) used reactive transport models to demonstrate that benzene found in contaminated waters related to the Divide Creek seep (nearly 4000’ from its source) could maintain the measured concentrations only if the rate of transport was significantly enhanced by a conduit and described local fracture networks as the most likely conduits. Thyne (2008) explained that fluid migration is further enhanced by proximity to structural features like folds and their associated fractures, noting in his study that “The locations of the most affected [wells] are near structural features where the faults and fractures maximize the vertical mobility of the gas,” and that “most problem wells...[are] coincident with the Divide Creek Anticline” and “increased fracturing near the anticline...may affect water resources.” It’s important to note that Divide Creek Anticline is underlain by deep-seated thrust faults (Tyler, 1996), similar to the Basin Syncline where the proposed injection zone is found. A more comprehensive review of geochemical studies documenting groundwater contamination events facilitated by geologic structures and/or oil and gas development has been compiled by Greg Oberley and is included as an appendix to this document.

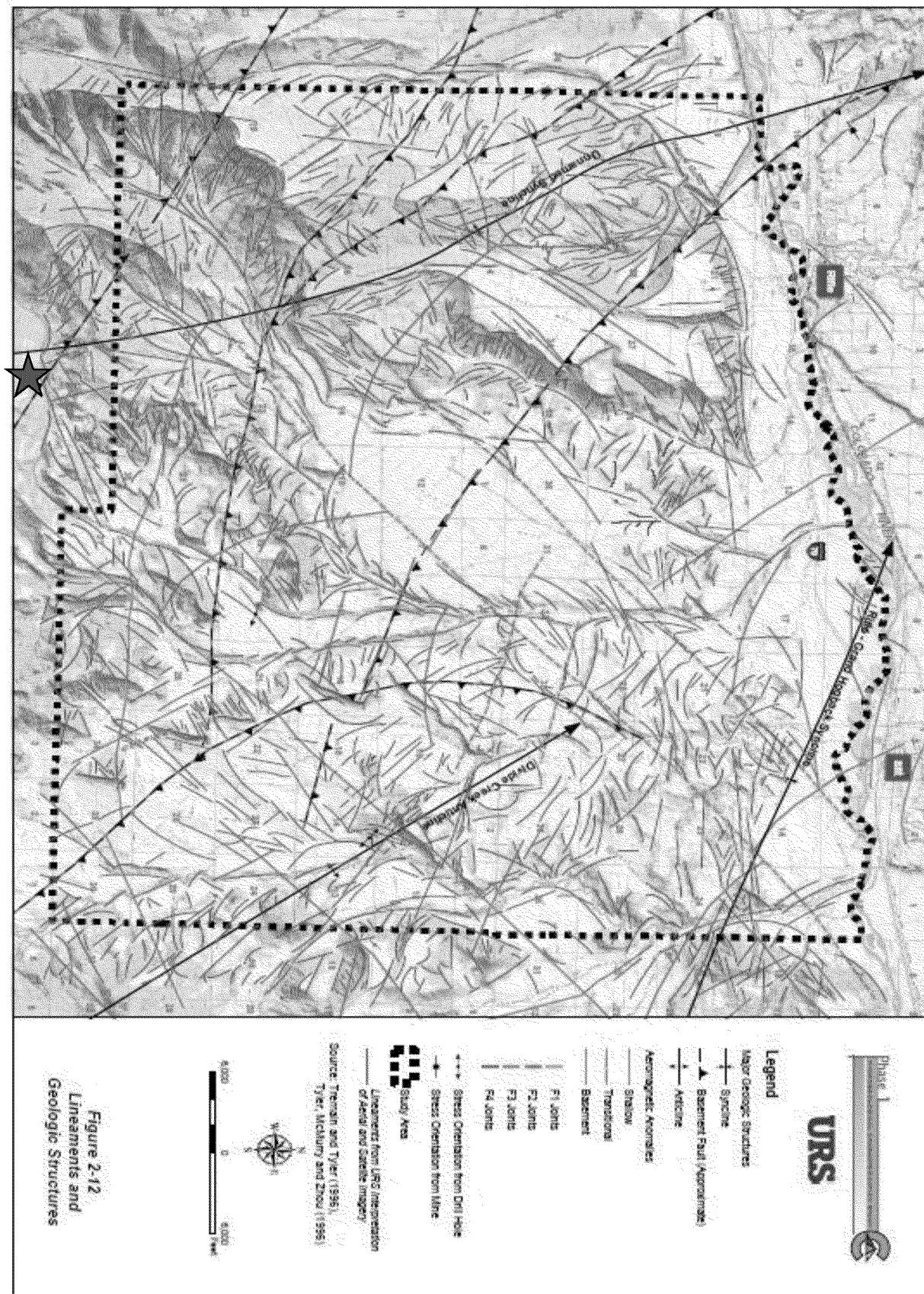
#### **Summary of Significant Concerns with the Proposed Injection**

1. There is no convincing evidence supporting the statement that the Shire Member contains a laterally continuous effective confinement zone above the proposed injection zone
  - a. Permeability and porosity of mudstones is difficult to determine, highly variable, and dependent on lithology (grain size & distribution) (eg., Yang and Aplin, 2007)
  - b. The Shire Member is composed of up to 20% sands, in combination with paludal (marsh) and floodplain muds (URS 2006), indicating a variable and mixed lithology/grain size, as further demonstrated by Encana’s (2015) MCU Injection Stratigraphic Cross-Section
  - c. Drinking water wells in this part of the basin are screened in the Wasatch, with approximately 1/3 of those in the Shire Member (URS 2006)

2. Even if a demonstration of sufficient primary permeability and lateral continuity of a confining interval within the Shire Member were provided, the more important factor limiting the containment of fluids within the proposed injection zone is the significant evidence of secondary porosity and permeability related to extensive faulting and fracturing in the area around the well as documented in the literature described above. Of particular concern is documented evidence of conjugate fracture sets and evidence of fluid migration through fractures identified within Wasatch mudstones in the URS (2006) study
3. Geochemical studies of the groundwater in the area demonstrate existing deep fluid migration and groundwater mingling events resulting from a combination of geological features and industry practices
4. Absent a detailed analysis of fluid movement in the proposed injection zone, the applicant is not able to demonstrate that the injected fluids will remain within that zone
  - a. Additional data from the applicant may help determine whether local geologic features such as faults and fractures exist in the immediate vicinity of the wellbore:
    - i. FMI from proposed or nearby wells (for fault and fracture orientation and projection)
    - ii. Temperature log(s) from proposed well which may help identify zones of fluid movement or lack thereof
    - iii. Detailed daily drilling reports from proposed well to identify any shallower lost circulation zone
    - iv. Mudlog from proposed well

Figure 1. Geologic Structure and lineaments (from URS, 2006).

★ Approximate Location of Wieben well



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## APPENDIX (Fluid migration and chemistry review by Greg Oberley)

### Mamm Creek Wasatch Formation Fluid Migration

Ground Water Quality – Evidence for Migration of fluids from Williams Fork/Mesa Verde into Wasatch formation and shallow Wasatch formation drinking water wells and lower Wasatch formation into shallower Wasatch formation used for drinking water. Evidence from EPA analysis of water quality changes over time and USGS reports documenting fluids from the Mesa Verde formation and lower zones within the Wasatch formation have moved vertically into shallower zones of the Wasatch formation where drinking water wells are screened.

It should be noted that drinking water wells for the purposes of ranching (including domestic, stock and irrigation are only drilled as deep as necessary. The depth of these wells is not an indication of nor does it define the vertical extent of useable drinking water zones within an aquifer or USDWs. The following is a synopsis of earlier EPA presentations and USGS reports on water quality.

- Past EPA presentations
  - Water quality presentations on Chloride changes overtime (pre and post 2002)
  - Water quality presentations on dissolved methane changes overtime (pre and post 2002)
- USGS 2010 Report statements concerning potential fluid movement in the subsurface

“The co-occurrence of high concentrations of methane and helium-4 implies the biogenic methane also was derived from a deep source. One sample containing high concentrations of biogenic methane and helium-4 had water-isotopic and major-ion compositions similar to that of water from the underlying Mesaverde Group, which was the primary natural-gas producing interval in the study area. Methane from the Mesaverde Group was largely thermogenic in origin so biogenic methane in the sample was more likely derived from deeper zones in the Wasatch Formation.”

This statement demonstrates that there is evidence of fluid movement throughout the Wasatch formation from deeper to shallower zones including to the shallower zones in which drinking water wells are screen and from which the samples were collected.

“Water from the Mesaverde Group could incorporate biogenic methane from the deep Wasatch Formation before entering the shallow Wasatch Formation if it moved through natural fractures or uncemented annular space in gas wells that intersected zones enriched in biogenic methane.”

This paragraph interprets data for the dissolved methane isotopic signature to be biogenic and from the lower Wasatch comingling with Mesa Verde formation liquids and again finding its way into the upper zones of the Wasatch used for drinking water.

“The north-south trending zone where domestic wells produced water with high methane and helium-4 concentrations generally coincided with known geologic structures such as the Divide Creek anticline, Rifle-Grand Hogback syncline, and deep faults, and they could be pathways for water and gas migration.”

This paragraph relates the movement of fluids potentially to structural features within the Piceance



Basin. USGS is noting that not all structural features that could provide a migration pathway for fluids are solely related to the Divide Creek anticline.

“A compilation of data on surface-casing depths in 924 gas wells done by URS Corporation (2006) showed a median casing depth of 260 m, which is probably several hundred meters above the base of the Wasatch Formation in the high methane zone. Presumably, the annular space in those wells was uncemented between the bottom of the surface casing in the Wasatch Formation and the top of cement used to seal the gas-producing interval in the Mesaverde Group (URS Corporation, 2006). Some of those uncemented intervals could contain high concentrations of biogenic methane and act as pathways for water and gas migration.”

Here the USGS author is generally describing the potential for uncemented well bores in the Wasatch to contribute to fluid migration. What the authors did not mention as EPA analyses have previously pointed out, is that there are many well bores that are not cemented across the upper Williams Fork formation (with gas zones present) and extend into the Wasatch to zones below the surface cased hole.

□ Papadopolus and URS reports

□ Schwartz well event

- The Schartz well event was a cement loss episode where large volumes of cement disappeared into a deep formation.
- The Schwartz well event dramatically demonstrated fluids moving from depths in the Williams Fork formation can reach shallow zones in the Wasatch, including the surface.
- The premise was that the well intersected a large fracture network and the wellbore provided a pathway for Mesa Verde fluids to migrate to the surface through fracture systems within the Wasatch.
- This demonstrates that fluid loss zones are not necessarily confined as Encana is claiming. In fact, fluid loss zones may be connected to shallow zones within the Wasatch and as was demonstrated by the Schwartz well event can even move fluids to the surface.
- This event was detected by visual observations at the surface and not by direct subsurface monitoring on the part of the operator or COGCC. Many other “lost circulation” events and pressure “kick” events in the Mamm Creek field have occurred.
- These events have been addressed without understanding the potential for fluid migration to impact shallow groundwater zones until evidence reaches the surface and is visually observed.
- When fluid loss or pressure kicks occur it is assumed by COGCC and the operator that no impact to useable groundwater has occurred because there were no observations, visual or otherwise. What this event points out (dramatically) is that the only time shallow groundwater is impacted is if you can visually determine it.

- Discussion of dissolved methane vs free methane migration
  - Methane vented from bradenhead casing annuli is undissolved methane or free methane
    - Free methane can either previously existed as dissolved methane; or
      - Existed as gas phase methane in a hydrocarbon reservoir; and
      - Moves through the subsurface as a buoyant gas with a large density differential from that of water.
    - Free gas within the Wasatch could move upward without any hydraulic head (vertical pressure) input.
      - It only requires a channel to flow through such as a fracture system, permeable fault zone, porous media or an open well annulus
      - Some of the free gas within the Wasatch could have moved out of the system many millions of years ago with some pockets still found that were not connected to the surface by a fracture system
    - Methane collected and analyzed in drinking water wells is dissolved methane
      - The distinction here is that dissolved methane has moved through the environment as part of the dissolved phase with liquids such as water
      - Movement of gas in a dissolved phase requires that there be a fluid pressure differential or a hydraulic head difference.
      - Again circulation loss zones and pressure kick zones are examples of potential pressure drive zones if they are not properly isolated.
  - Venting addresses the build-up of free methane or fluids with dissolved methane entering the open annulus
    - It may not address potential for liquid fluid movement containing dissolved gases and chloride
  - Fracture systems within the Wasatch formation provide pathways for fluids migration that are more similar to flow in a pipe or planar sheet flow vs porous rock matrix flow of Mesa Verde fluids
- How this information resulting from a very complex geologic system should influence design and installation of production wells
  - Since existing sampling demonstrates the Mesa Verde or Williams Fork formation fluids are found in shallow groundwater zones used for drinking water Well construction needs to consider:
    - Preventing Williams Fork formation fluids from entering shallower Wasatch formation zones that are currently being used for drinking water. This has been done with the new requirement to cement production casing in all wells from TD to 500 feet above the top of the Williams Fork formation.
    - Preventing non-commercial gas bearing zones in contact with a well bore to communicate fluids into shallower zones used for drinking water. Since it is claimed by COGCC that these zones can exist throughout the Wasatch formation, EPA believes that well bores within the entire Wasatch formation

should also provide full zonal isolation. Currently this problem is approached by venting the bradenhead which relieves pressure created by free gas found within the bradenhead.

- Preventing liquid fluid flow within the bradenhead caused by hydraulic head pressure differences. Some wells with the study area exhibit liquid flow at the surface. This phenomena demonstrates that in addition to the potential for gas pressure to cause fluid movement into shallower zones below the surface casing shoe, that hydraulic head pressure can exist at depth high enough to move water from deep zones to shallower zones.
  - The practice of fracturing isolated sand lenses within the Williams Fork could be connecting natural fracture systems allowing for upward migration of undissolved or free gas to move upward due to the buoyancy of the gas. According to COGCC this potential migration due to buoyancy is counter balanced by producing the well and providing a steeper gradient with lower pressure in the direction of the well. Except for when the well is shut-in or any status where the well is not producing, or plugged and abandoned.
  - EPA recommends fully casing and cementing the entire well bore for the Williams Fork formation (production formation) through the Wasatch formation to 50 feet above the bottom of the surface casing. This should be accomplished with either one casing string or two casing strings using intermediate casing.
- How this information summary should influence disposal well practices
    - Disposal well construction should embrace cementing the Williams Fork and Wasatch formations to a point above the surface casing shoe.
    - Since natural structural geologic features exist through-out the basin that allow for the verticle movement of fluids within the Wasatch formation, as has been demonstrated by USGS and others for the Piceance basin and specifically within the Mamm Creek field and study area, confinement of injection fluids within a particular lithologic zone within the Wasatch formation is unlikely and cannot be demonstrated.
    - Since there are already a number of injection wells within the Mamm Creek field that are injecting below the Williams Fork formation EPA suggests that disposal well be permitted for injection into the Corcoran and Cozzette formations do not require aquifer exemptions and demonstration of confinement is possible.
  - Critical pressure determination
    - The suggested method of determining a critical pressure for bradenhead pressure in wells was not included in the report
    - 150psi is way too high for wells with shallow surface casing. In fact the shallower the surface casing the more endangered the shallow groundwater become due to the relatively high pressure at a shallower depth. Interestingly not only is the 150psi critical pressure not a conservative value but the value exposes shallower ground water to more risk that wells with deeper surface casing. One would assume that you would want to give more protection to the shallower zones where groundwater is being used.

- It's not conservative to be conservative to need to start with the shallowest surface casing and adjust critical pressure to that depth – another example of a failure to use flexibility to the calculation correctly or at least fall back to a conservative value and 150 psi ain't it.
- **New comment may not be appropriate:** In some cases you could argue that if you permitted an injection well at the depths of the surface casing shoe into the Wasatch based on permitted MAIPs for existing wells 150psi would be above the MAIP. Demonstrating that their method of determining a critical pressure is not a supportable method. (Injection above an MAIP would indicate definite fluid movement just below the frac pressure.
- Anticipating future development of the Niobrara formation
  - In light of the potential for mineral development of deeper resources appropriately designing well construction to accommodate future development seems to be a best management practice. Design of casing and cement that may be incrementally more now may prevent huge existing retrofit costs during future development.